The Use of Pb-210, Th-234 and Cs-137 as Tracers of Sedimentary Processes in San Francisco Bay, California

by

Christopher Channing Fuller

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Christopher Channing Fuller

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This thesis, written by

Christopher Channing Fuller

under the direction of his *Thesis Committee, and approved by all its members, has been presented to and accepted by the Dean of The Graduate School, in partial fulfillment of the requirements for the degree of*

Master of Science

Dean

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DEDICATION

This thesis is dedicated to the memory of my father, John Channing Fuller, whose wisdom and love of nature inspired me to pursue studies of the environment.

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ABSTRACT

The partitioning of Pb-210, Po-210, and Th-234 between the dissolved (<0.4μ) and solid phases in the water column of San Francisco Bay is presented. Profiles of Pb-210, Th-234, and Cs-137 in sediments are also presented. These data were used to determine residence times and resuspension rates of suspended sediment particles, sediment accumulation and mixing rates, and to further the knowledge of the geochemical behavior of these isotopes in estuarine environments.

An uptake rate constant for the scavenging of Th-234 from solution onto particles of 1.5±0.6 day^{-1} is calculated from the average dissolved Th-234 activity, .04±.01 dpm/l, and its production rate by the decay of U-238. It is unclear whether this removal is due to reversible or irreversible adsorption. Residence times of suspended particles in surface waters ranging from 1 to 21 days are calculated from the mass balance of Th-234 in the water column and average 6.8±4.5 days for the South Bay and 11±10 days for San Pablo Bay. If the input of excess Th-234 by resuspension of bottom sediments is included, particle residence times of 3.5±2.2 days for the South Bay and 5±3 days for San Pablo Bay are calculated. Water column samples from near the bottom yield longer residence times, which probably reflect near bottom transport of particles from shallow to deep regions. Resuspension rates of 1.1±1.4 gm/cm^{2}yr for deep areas of South Bay, 0.7±1.0 for shallow areas of South Bay, and 0.7±1.0 for the deep areas of San Pablo Bay are calculated from the distribution of Th-234 in the water column and sediment. Comparison

of these rates to accumulation rates suggest sediments are resuspended at least 2 to 5 times before final burial in the deep areas of South Bay.

Surface sediment mixing rate constants calculated from Th-234 sediment activities range from 1 to 10 x 10^{-5} cm^2/sec at deep stations of the South Bay. The shallow reaches yield rate constants of less than 1 x 10^{-7} cm^2/sec. Live polychaetes, observed to 60 cm in cores from the deep area, may be responsible for much of the sediment reworking. In San Pablo Bay sediments, where live benthic macrofauna were not observed, Th-234 indicates little or no sediment mixing. Integrated excess Th-234 activities in sediments at the deep stations of the South Bay have a 2 to 18-fold greater activity than can be supported by the decay of U-238 in the overlying water column. This suggests that these areas accumulate Th-234 and sediments from the adjacent shoal areas.

An inverse relationship betweeen dissolved and suspended particle Po-210 activities suggests an irreversible scavenging of Po-210 from solution. Pb-210, however, shows an opposite trend, which is modelled as an equilibrium partitioning. Overall distribution coefficients of 1.3±.1 x 10^5 cm^3/gm for high salinities (>24°/₀₀) and 2.8±.3 x 10^5 for low salinities (<18°/₀₀) are calculated and are used for determining suspended particle excess activities from total (unfiltered) water samples. A seasonal variation in excess Pb-210 activity on suspended particles ranging from 1.9 dpm/gm during low fresh water inflows and 3.8 dpm/gm during high flows is observed. The elevated activities during high flows are similar to those measured in river water above the null zone of the estuary. Po-210 and Pb-210 activity ratios in total water samples range from 0.6±.1 to 1.2±.1 in both bays. The lower values measured during high fresh water inflows probably reflect the atmospheric source of excess Pb-210. Suspended particle activity ratios are generally higher than total samples indicating a preferential removal of Po-210 over Pb-210 from solution.

Excess Pb-210 in the sediments of the deep areas of South and San Pablo Bays extends much farther down core (up to 130 cm) than in the shallow reaches (10 to 20 cm). Upper limits of recent sediment accumulation rates are estimated from the integrated excess Pb-210 in the sediment column and the excess Pb-210 activity of suspended particles. These range from 0.03 to 0.10 gm/cm^{2}yr in the shoals and 0.13 to 0.53 gm/cm^{2}yr in the deep areas of the South Bay., Rates in San Pablo Bay range from 0.06 to 0.11 gm/cm^{2}yr in the shoals and 0.9 to 1.0 gm/cm^{2}yr in the deeper areas. However, numerical modelling of Pb-210 profiles using mixing and resuspension rates derived from Th-234 data shows that the combination of deposition, resuspension, and mixing can produce profiles observed in the shallow areas. In the deep areas modelling shows that some net deposition is required. These results indicate that an influx of new sediment particles to the sediment column can be maintained without net deposition and that the accumulation rates based on a Pb-210 mass balance are upper limits.

An atmospheric Pb-210 flux of 0.15 dpm/cm^{2}yr for the San Francisco Bay area was measured with artificial collectors. This rate agrees well with the rate of 0.12 determined by integrating the Pb-210 excess in a salt marsh core. A flux of 0.23 dpm/cm^{2}yr was measured in the Los Angeles area with collectors. The higher flux in Los Angeles is probably due to a two fold greater rainfall during the collection period than in the Bay area. Both fluxes are significantly lower than Turekian et al's (1979) global model predicts. Bay-wide sediment and Pb-210 budgets suggest that the measured flux is more realistic than the model predicted flux.

The depth of Cs-137 activity in sediments and their integrated activities show geographic variability similar to that observed for Pb-210. An enhanced penetration of Cs-137 to equal or greater depths than excess Pb-210 is observed in cores with abundant active polychaete burrows. This may be the result of irrigation and/or radial diffusion out of the burrows. Cs-137 activity profiles show no distinct maxima that can be correlated with temporal variations in fallout delivery. Their absence is probably due to sediment mixing and the temporal input of Cs-137 bearing particles from the drainage basin. The inventory of Cs-137 in the South Bay is 60% of the amount supplied by direct fallout. In San Pablo Bay, the inventory is twice the amount delivered by fallout. In the Central Bay, the inventory is equal to the activity delivered by direct fallout. Since a significant fraction of the fallout Cs-137 is flushed out of the bay in the dissolved phase, a large input of Cs-137 derived from the drainage basin is required to support the observed activites.

Bay-wide Pb-210 inventories indicate that direct fallout supplies 55% of the excess Pb-210 in South Bay sediment, 30% in San

Pablo Bay and 40% in the Central Bay. Assuming that the input of suspended sediment from local rivers and streams (with an excess Pb-210 activity equal to that measured in river water) is the only other source of Pb-210, $1.0 \pm .4 \times 10^{11}$ gm/yr of sediment must be deposited in the South Bay to maintain the observed Pb-210 activity. This is 33% of the sediment supplied by local streams. For San Pablo Bay, $2.2 \pm .3 \times 10^{11}$ gm/yr of sediment from local streams and rivers and from delta sources is required. This input accounts for 85% of the sediment delivered by the local sources. The Central Bay requires $0.8 \pm .3 \times 10^{11}$ gm/yr of sediment from local stream and delta sources. These required inputs result in overall accumulation rates of 0.03 gm/cm^{2}yr for the South bay, 0.10 gm/cm^{2}yr for muddy areas of the Central Bay and 0.11 gm/cm^{2}yr in San Pablo Bay. Earlier sediment budgets, which suggested net erosion in the South Bay based on changes in bathymetry, may be in error because they fail to account for recent sea level rise and local subsidence.